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(54) **ELECTRO-OPTICAL COMPONENT**

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372/96; 257/18, 103

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(57) **ABSTRACT**

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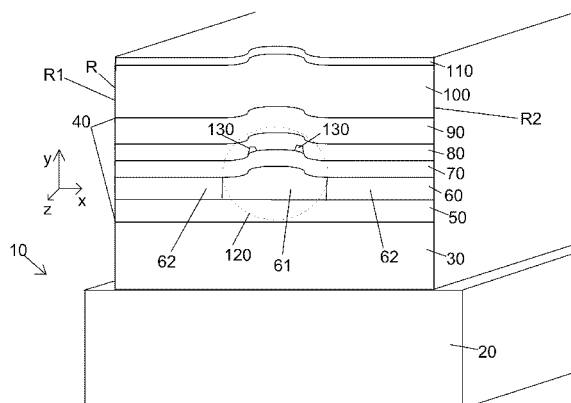
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CPC ..... **H01S 5/183** (2013.01); **B82Y 20/00**  
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CPC ..... G02B 6/4214; H01S 5/18311; H01S  
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The invention relates, inter alia, to a method for producing an  
electro-optical component (**10, 200**) suitable for emitting  
electromagnetic radiation (**120**), wherein in the method  
a first intermediate layer (**60**) is applied on a carrier,  
a second intermediate layer (**70**) is applied on the first  
intermediate layer, and  
after the second intermediate layer has been applied, the  
buried first intermediate layer is locally modified,  
wherein as a result of the local modification of the buried  
first intermediate layer in a lateral direction a refractive  
index jump is produced which brings about a lateral  
wave guiding of the electromagnetic radiation (**120**) in  
the unmodified region of the first intermediate layer.

**13 Claims, 9 Drawing Sheets**



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**H01L 33/00** (2010.01)

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**2924/0002** (2013.01); **H01S 5/18325** (2013.01);  
**H01S 5/204** (2013.01); **H01S 5/2031** (2013.01);  
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 (2013.01)

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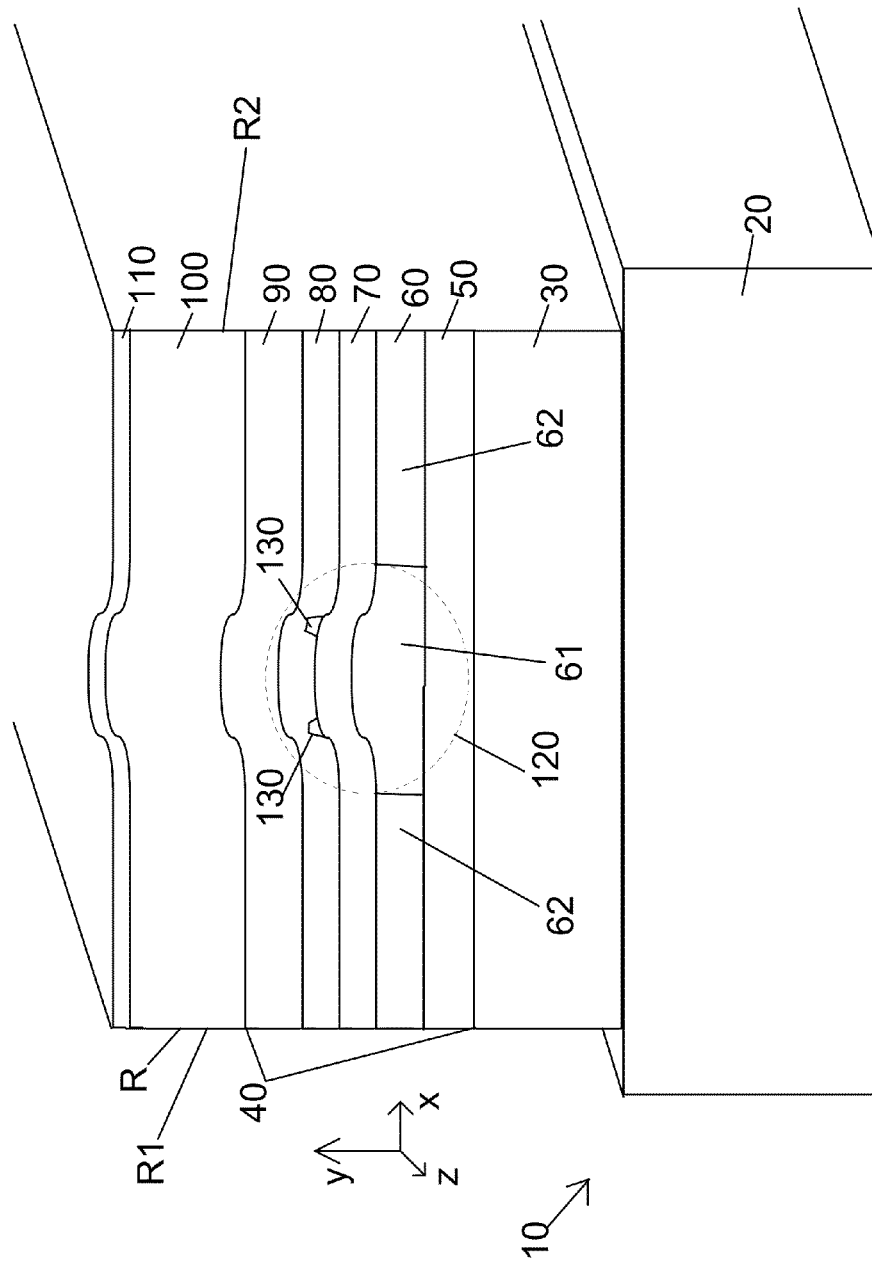


Fig. 1

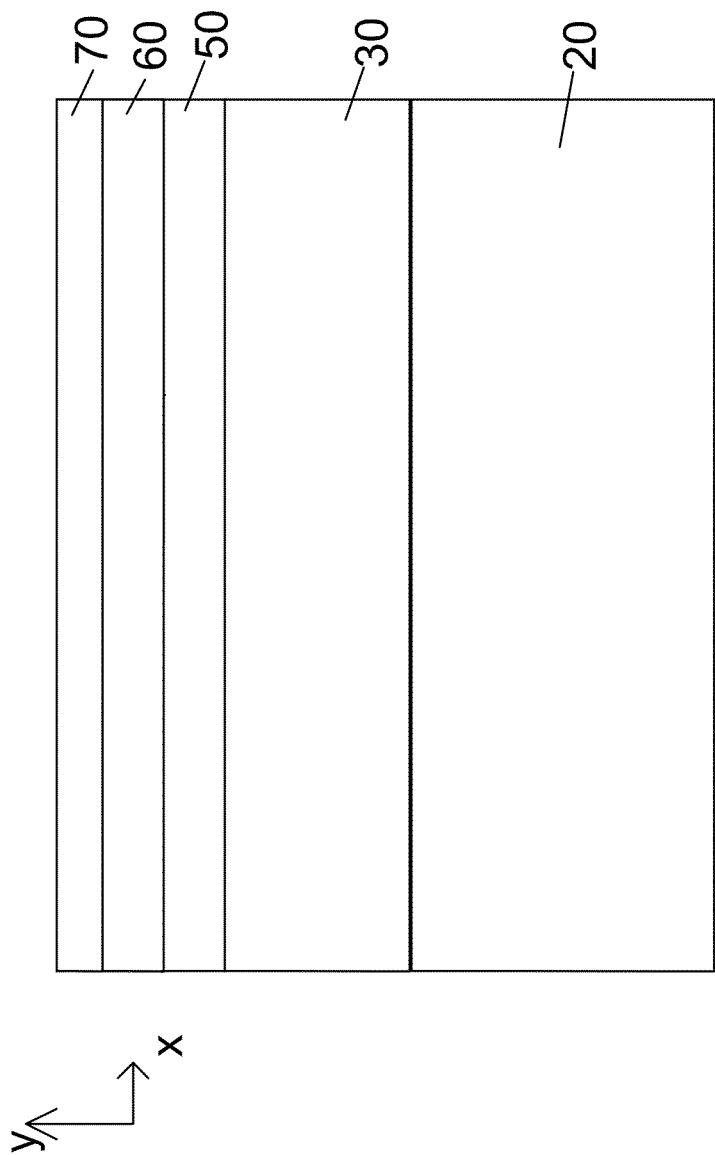


Fig. 2

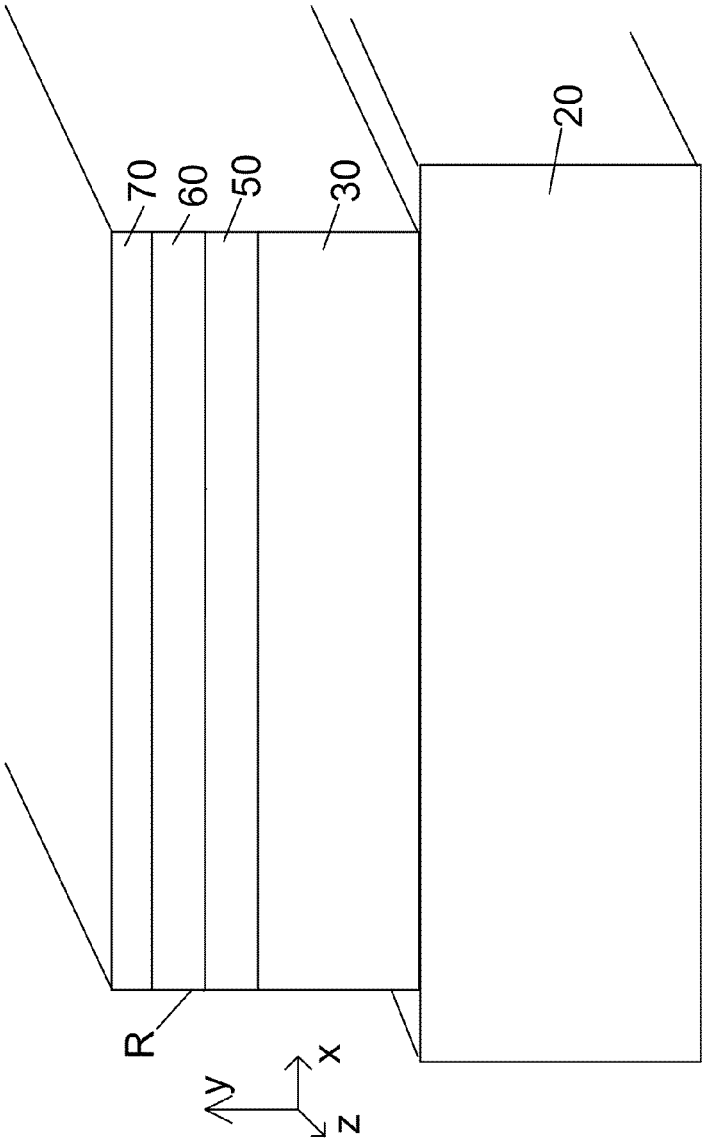


Fig. 3

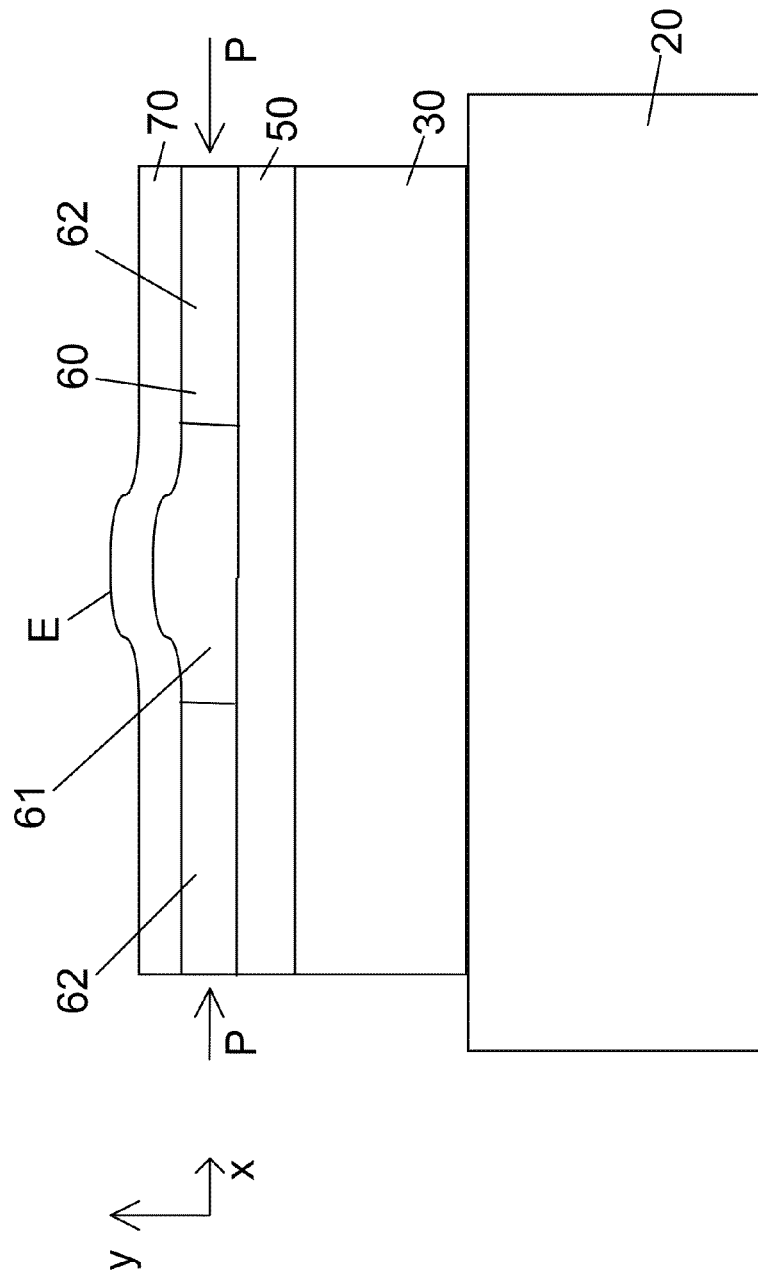


Fig. 4

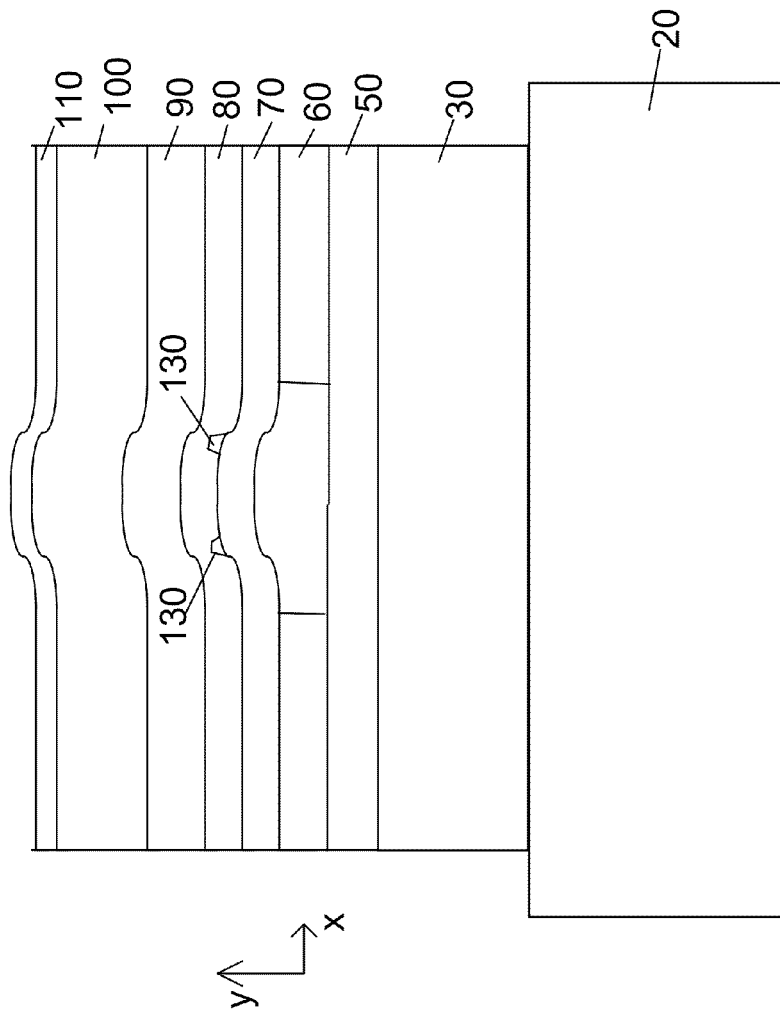


Fig. 5

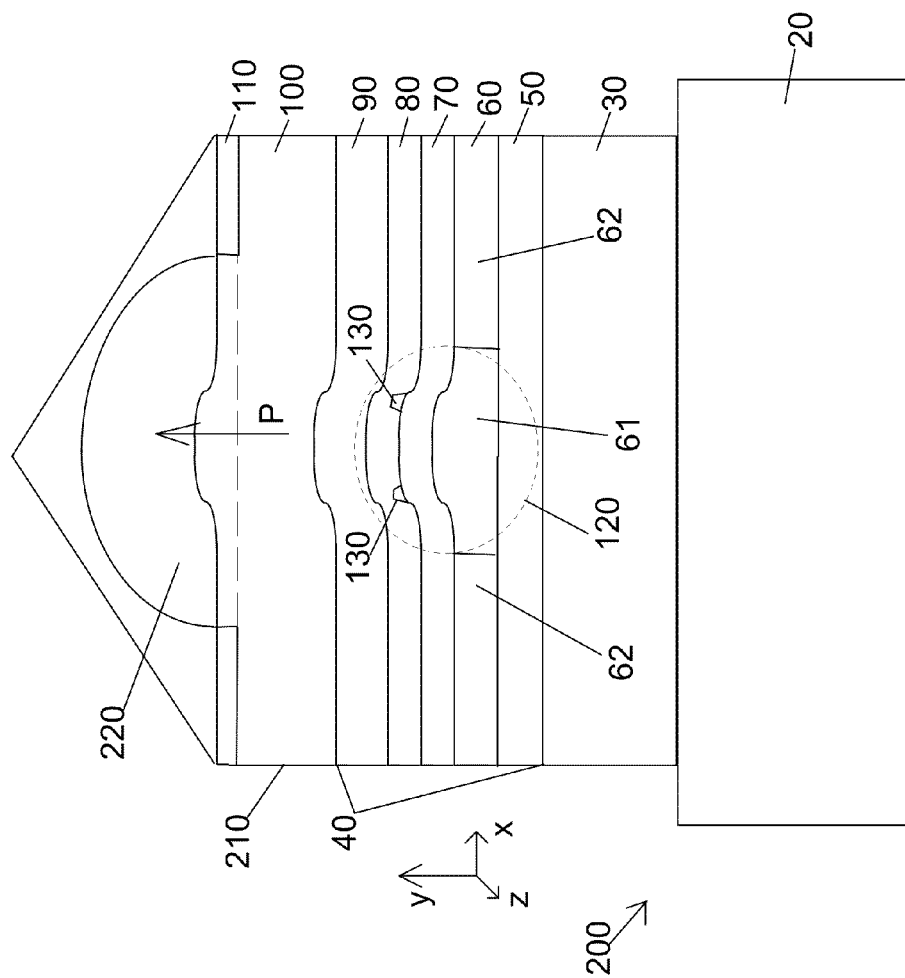


Fig. 6

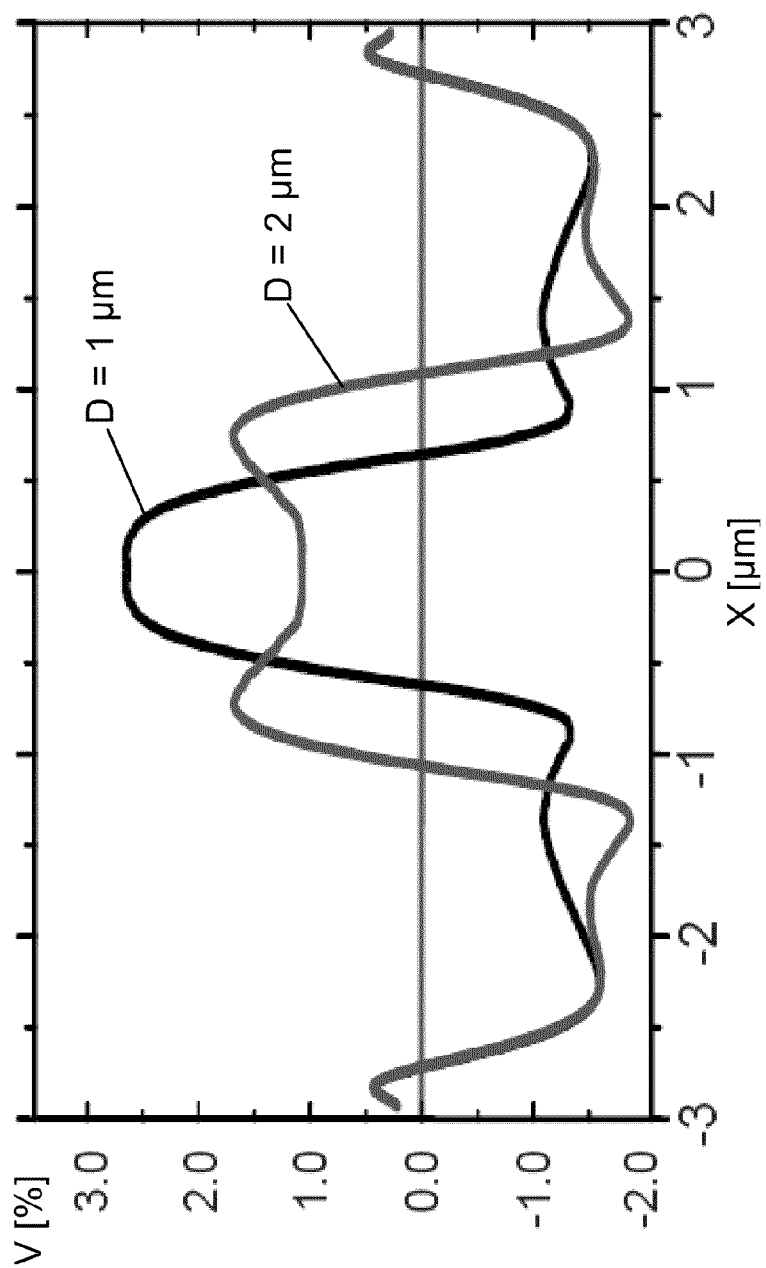


Fig. 7

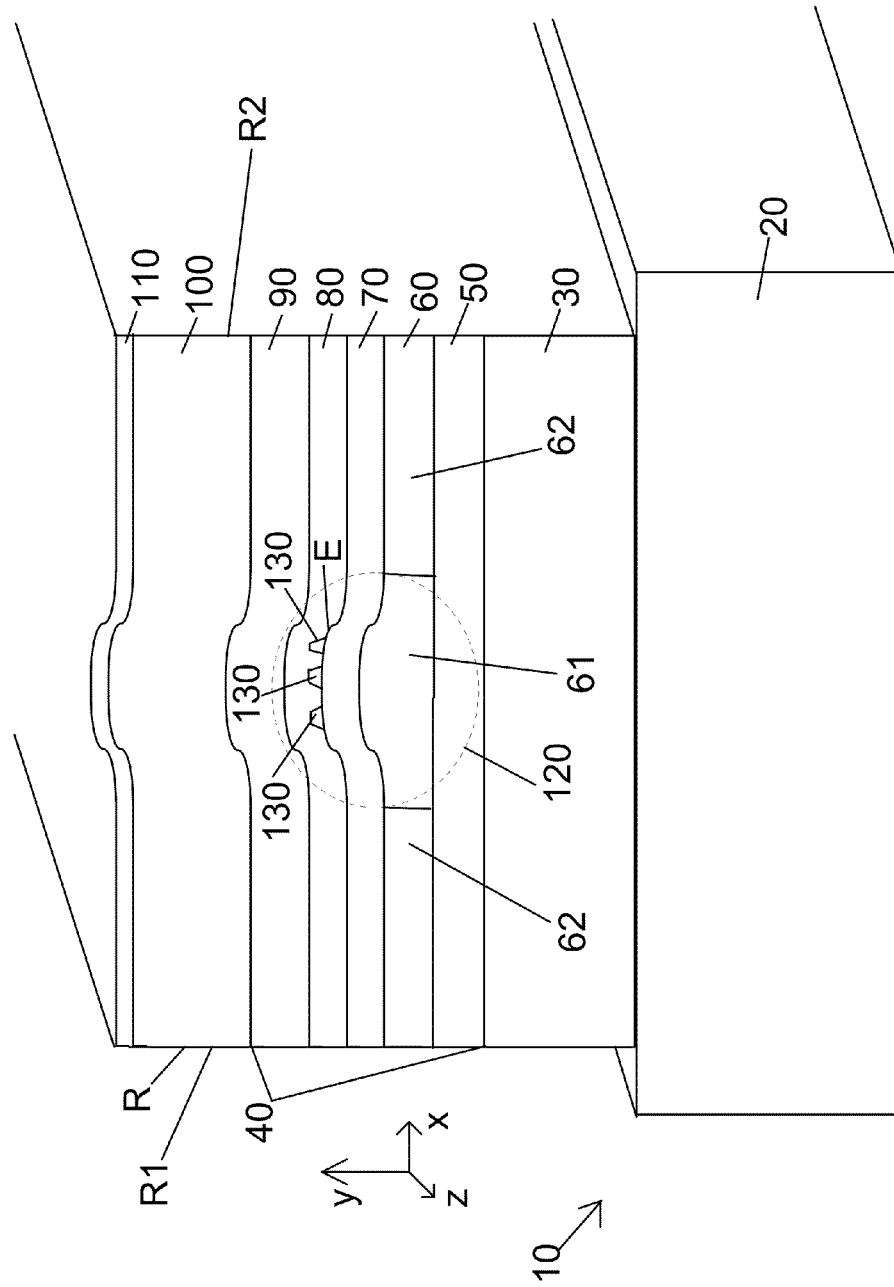


Fig. 8

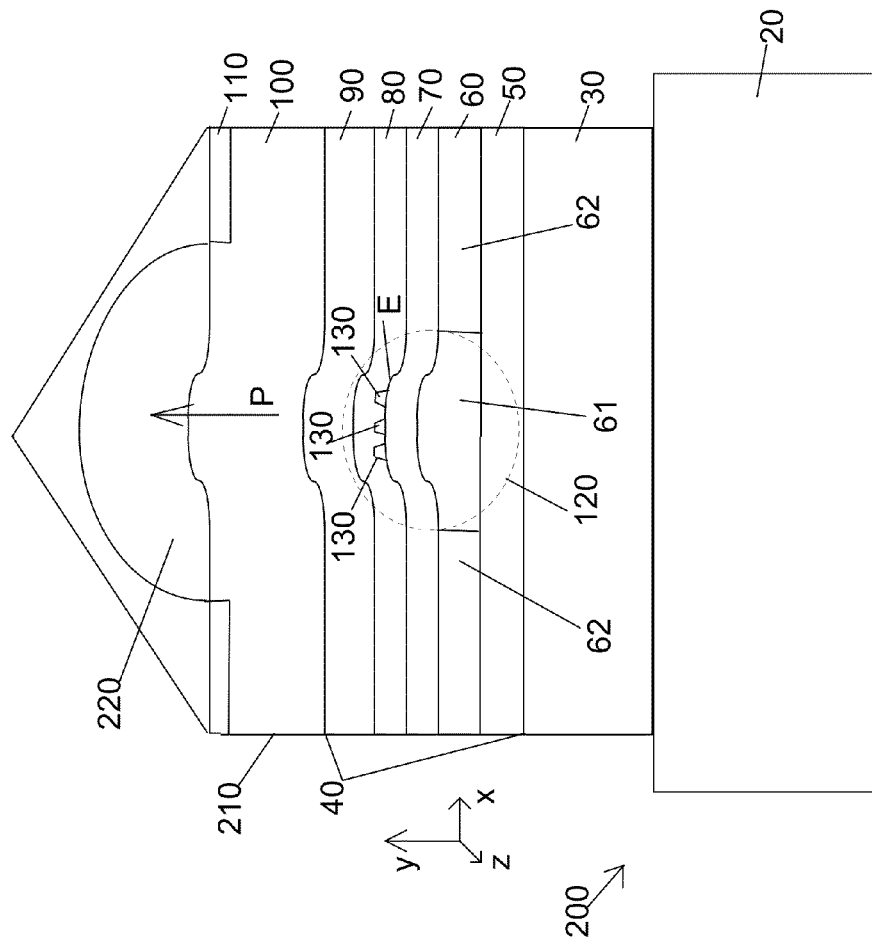


Fig. 9

## ELECTRO-OPTICAL COMPONENT

The invention relates to a method for producing an electro-optical component suitable for emitting electromagnetic radiation.

A method of this type is known from the International Patent Application WO 2007/062625. In the previously known method, lateral flanks are etched. In addition, a current aperture is formed which defines the electrically excited volume during operation.

The invention is based on the object of specifying a method with which even better properties can be achieved for the electro-optical component.

This object is achieved according to the invention by means of a method comprising the features as claimed in patent claim 1. Advantageous configurations of the method according to the invention are specified in dependent claims.

Accordingly, it is provided according to the invention that a first intermediate layer is applied on a carrier, a second intermediate layer is applied on the first intermediate layer, and, after the second intermediate layer has been applied, the buried first intermediate layer is locally modified, wherein as a result of the local modification of the buried first intermediate layer in a lateral direction a refractive index jump is produced which brings about a lateral wave guiding of the electromagnetic radiation in the unmodified region of the first intermediate layer.

One essential advantage of the method according to the invention is that in the context of the local modification of the buried first intermediate layer in a lateral direction a wave guiding is produced. What can be achieved by this lateral wave guiding is that the electro-optical radiation is guided primarily or exclusively in the inner region of the component and in particular cannot (or at least cannot significantly) pass into the region of outer, for example etched, edges, and so the attenuation of the electro-optical radiation is minimized.

A further essential advantage of the method according to the invention is that as a result of the local modification of the buried first intermediate layer, besides the wave guiding already discussed, at the same time it is also possible to achieve a current focusing in that region of the component in which the first intermediate layer guides the electro-optical radiation. Consequently, in an advantageous manner, by way of example, both a lateral waveguiding and an electric current aperture can be produced as a result of the step of local modification.

Preferably, the local modification of the first intermediate layer causes a strain both in the first intermediate layer and in the second intermediate layer situated thereabove and forms an elevation above an inner semiconductor region of the first intermediate layer.

Preferably, a third intermediate layer is applied on the second intermediate layer, wherein nanostructures are formed on the second intermediate layer as a result of the strain in the first and second intermediate layers.

In one preferred configuration of the method, the nanostructures are formed in the region of the outer edges of the elevation on the second intermediate layer, to be precise on account of the strain caused previously in the region of the outer edges of the elevation.

In order to produce the strain in the region of the outer edges of the elevation, which strain is advantageous for forming the nanostructures, it is regarded as advantageous if the lateral diameter of the elevation - measured in the plane of the first intermediate layer is greater than 1.5  $\mu\text{m}$ . Preferably, the diameter lies in the range of between 1.5  $\mu\text{m}$  and 2.5  $\mu\text{m}$ .

Alternatively, the nanostructures can be formed on the second intermediate layer on account of the strain in the central region of the elevation. In order to produce the strain in the central region of the elevation, which strain is advantageous for forming the nanostructures, it is regarded as advantageous if the lateral diameter of the elevation—measured in the plane of the first intermediate layer—is a maximum of 1.5  $\mu\text{m}$ .

The third intermediate layer preferably forms the active zone of the component in which radiation is generated.

Preferably, quantum dots or quantum films are formed as nanostructures.

It is regarded as particularly advantageous if as a result of the local modification of the buried first intermediate layer in a lateral direction a refractive index jump is produced symmetrically about an optical axis (e.g. an axis of symmetry) of the component, as a result of which the lateral waveguiding is effected symmetrically with respect to the optical axis. In this configuration, the local modification of the buried first intermediate layer can therefore cause an optical centering of the optical component about a predefined optical axis, for example an axis of symmetry of the component.

Preferably, a third intermediate layer is grown epitaxially on the second intermediate layer after the local modification of the first intermediate layer. This configuration of the method makes it possible for the third intermediate layer to remain unaffected by the step of local modification of the first intermediate layer, and in particular not to be altered or impaired by or during the modification of the first intermediate layer.

It is furthermore regarded as particularly advantageous if as a result of the local modification of the buried first intermediate layer at least one section of the second intermediate layer situated thereabove is locally mechanically strained and at least one material parameter of the third intermediate layer is location-dependent on account of the local strain in the second intermediate layer (for example symmetrically about the optical axis of the component). In this configuration, the local modification of the first intermediate layer not only achieves a lateral waveguiding but furthermore also influences the material properties of the third intermediate layer situated thereabove. In this regard, a local strain can cause or support for example the formation of nanostructures (e.g. quantum wires, quantum dots or quantum films (in the jargon also called “quantum wells”)) in the third intermediate layer.

Preferably, on account of the location dependence of one or more material parameters of the third intermediate layer, one or more local minima are produced in the electronic transitions of the third intermediate layer. The minimum or the minima of the electronic transitions is/are preferably arranged symmetrically about the optical axis of the component.

In connection with the modification of the first intermediate layer, it is regarded as advantageous if a section of the second intermediate layer is removed and the buried first intermediate layer is exposed in sections and the intermediate layer exposed in sections is chemically modified before the third intermediate layer is grown epitaxially on the second intermediate layer. The modification of the first intermediate layer in sections can be effected for example by oxidation or nitration (nitriding).

It is additionally regarded as advantageous if the chemically modified section of the first intermediate layer is electrically nonconductive or only poorly conductive and has a lower refractive index than the unmodified section of the buried first intermediate layer. In this method variant, both an

electric current aperture and a lateral waveguiding can be constrained in a single method step.

The electro-optical component can be laterally mono-modal or laterally multimodal with regard to the emitted electromagnetic radiation. The lateral mode or the lateral modes of the electromagnetic radiation is/are preferably defined by the lateral waveguiding of the unmodified region of the buried first intermediate layer.

Preferably, the thickness of the buried first intermediate layer and the lateral dimension of the unmodified section of the buried first intermediate layer are chosen in such a way that the lateral mode or the lateral modes of the electromagnetic radiation is/are defined by the unmodified region of the buried first intermediate layer.

Preferably, the electromagnetic radiation is generated exclusively, at least approximately exclusively, in that region of the third intermediate layer which is situated above the unmodified section of the first intermediate layer. In this configuration, a particularly large overlap occurs between the lateral wave guiding in the first intermediate layer and the optical emission (or photon generation) in the third intermediate layer. In this case, the local generation of the electromagnetic radiation in the region above the strained section of the second intermediate layer is preferably effected by a parameter change within the third intermediate layer on account of the strain in the second intermediate layer.

Preferably, a mechanical strain is locally induced in the second intermediate layer and the third intermediate layer as a result of the local modification of the first intermediate layer, said mechanical strain supporting or causing the formation of nanostructures during the deposition of the third intermediate layer.

The invention furthermore relates to an electro-optical component suitable for emitting electromagnetic radiation.

With regard to such an electro-optical component, according to the invention it is provided that said electro-optical component is equipped with a buried, locally modified first intermediate layer, in which as a result of the local modification in a lateral direction a refractive index jump is produced which brings about a lateral waveguiding of the electromagnetic radiation in the unmodified region of the first intermediate layer.

With regard to the advantages of the electro-optical component according to the invention, reference should be made to the above explanations in connection with the method according to the invention, since the advantages of the method according to the invention substantially correspond to those of the electro-optical component.

In accordance with one preferred configuration of the component, it is provided that the thickness of the buried first intermediate layer and the lateral dimension(s) of the unmodified section of the buried first intermediate layer are chosen in such a way that the lateral mode or the lateral modes of the electromagnetic radiation is/are guided by the unmodified region of the buried intermediate layer, a second intermediate layer is grown on the locally modified first intermediate layer and is locally strained as a result of the modification of the buried first intermediate layer, a third intermediate layer is grown epitaxially on the locally strained second intermediate layer, in which third intermediate layer at least one material parameter is location-dependent on account of the local strain in the second intermediate layer, and the electromagnetic radiation is generated exclusively or preferably in that region of the third intermediate layer which is situated above the strained section of the second intermediate layer.

The optical axis of the electro-optical component can be, for example, perpendicular to the surface of the substrate. Such a configuration is a "vertically emitting" optical component.

Alternatively, the optical axis can also run parallel to the surface of the carrier (or substrate): in such a configuration, the component can be an edge emitting component, for example. In order to achieve a waveguiding along the surface of the substrate, a ridge waveguide can be produced, for example, the longitudinal axis of which runs parallel to the carrier surface and/or parallel to the optical axis of the optoelectronic component.

Preferably, the substrate of the electro-optical component is a gallium arsenide substrate.

The invention is explained in greater detail below on the basis of exemplary embodiments; in this case in the figures, by way of example:

FIG. 1 shows an exemplary embodiment of an edge emitting electro-optical component according to the invention,

FIGS. 2-5 show production steps by which the component in accordance with FIG. 1 can be produced,

FIG. 6 shows an exemplary embodiment of a vertically emitting electro-optical component,

FIG. 7 shows by way of example the profile of the strain against the elevation for two different diameters of the elevation,

FIG. 8 shows an exemplary embodiment of an edge emitting electro-optical component in which the diameter of the elevation is chosen in such a way that nanostructures are formed in the central region of the elevation, and

FIG. 9 shows an exemplary embodiment of a vertically emitting electro-optical component in which the diameter of the elevation is chosen in such a way that nanostructures are formed in the central region of the elevation.

In the figures, the same reference signs are always used for identical or comparable components, for the sake of clarity.

FIG. 1 reveals an electro-optical component 10, which is a laser, for example.

The component 10 comprises a substrate 20, on which a lower waveguide cladding layer 30 is arranged. A waveguide core 40 is situated on said lower waveguide cladding layer 30, said waveguide core comprising a lower waveguide core layer 50, a first intermediate layer 60, a second intermediate layer 70, a third intermediate layer 80 and an upper waveguide core layer 90.

The substrate 20, the lower waveguide cladding layer 30 and the lower waveguide core layer 50 form a carrier, on which the first intermediate layer 60 has been applied.

The third intermediate layer 80 forms an active layer in which electromagnetic radiation is generated during the operation of the component 10.

An upper waveguide cladding layer 100 is situated above the waveguide core 40, an upper contact layer 110 being applied on said upper waveguide cladding layer.

The substrate 20 and the layers 30, 50, 60 (partly), 70, 80, 90 and 100 preferably consist of semiconducting material. The upper contact layer 110 can consist for example of a highly doped semiconductor material or of metal.

The doping of the substrate 20 and of the layers 30, 50 and 60 can be inverse for example with respect to the doping of the layers 90 and 100, in order to form a pn diode structure with which charge carriers can be injected into the active third intermediate layer 80.

The refractive index of the layers 50, 70, 80 and 90 of the waveguide core 40 is greater than that of the waveguide cladding layers 30 and 100, in order to achieve a waveguiding

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in a vertical direction. Examples of suitable material combinations for the layers **30** to **100** are explained further below.

The component **10** in accordance with FIG. **1** is an edge emitting component. For this purpose, the component **10** has a ridge **R** extending along the z-direction. The electromagnetic radiation is emitted in the z-direction (or counter to the z-direction) at one of the two (or at both) end faces of the ridge **R**.

The component **10** in accordance with FIG. **1** can be operated as follows:

If an electrical voltage is applied to the upper contact layer **110** and to the substrate **20**, a current flow through the waveguide core **40** occurs. On account of this current flow, photons are generated in the third intermediate layer **80** and lead to an electromagnetic radiation along the z-direction of the component **10**. The wave propagation of the electromagnetic radiation is identified by an ellipse bearing the reference sign **120** in FIG. **1**, which indicates the fundamental mode of the radiation generated by the component **10**. The fundamental mode extends along the ridge longitudinal direction along the z-direction out of the plane of the drawing.

The lateral waveguiding in the waveguide core **40** is caused by a refractive index jump in the first intermediate layer **60**. It can be discerned in FIG. **1** that the first intermediate layer **60** comprises a non-oxidized inner semiconductor region **61** and an oxidized outer region **62**. The refractive index of the inner semiconductor region **61** lies in the customary refractive index range for semiconductor materials of between 2 and 4, for example being approximately 3.5. The refractive index in the outer oxidized region **62** lies within the customary refractive index range for oxide materials of between 1 and 2, in other words for example being approximately 1.5. The very large difference in refractive indices between the inner semiconductor region **61** and the outer region **62** results in a waveguiding in a lateral direction, such that the electromagnetic radiation is guided exclusively, at least approximately exclusively, laterally in the inner semiconductor region **61**. Consequently, the electromagnetic radiation does not (or at least does not significantly) come into contact with the edges **R1** and **R2** delimiting the ridge **R** toward the outside.

The two different regions **61** and **62** in the intermediate layer **60** furthermore result in a current focusing (current aperture) in the inner semiconductor region **61**, specifically since the current flowing between the upper contact layer **110** and the substrate **20** has to flow through the inner semiconductor region **61** since the outer region **62** is oxidized and therefore nonconductive.

In order to generate the electromagnetic radiation in the exemplary embodiment in accordance with FIG. **1**, preferably nanostructures **130** (for example quantum wires, quantum dots or quantum films) are arranged in the active third intermediate layer in the region above the inner semiconductor region **61** of the first intermediate layer **60**, said nanostructures being excited in the case of a current flow and generating the electromagnetic radiation of the component. In this case, the arrangement of the nanostructures **130** is chosen in such a way that they are arranged substantially, preferably exclusively, above the inner semiconductor region **61** of the first intermediate layer **60** or have locally modified properties there. In the case of such an arrangement of the nanostructures **130**, a particularly high efficiency of the component is achieved since the entire current flowing through the component **10** preferably has to pass the nanostructures **130** on account of the current guiding through the inner semiconductor region **61**.

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An exemplary embodiment of a method for producing the component **10** will now be explained in greater detail in association with FIGS. **2** to **6**.

FIG. **2** reveals the substrate **20**, on which the lower waveguide cladding layer **30** and the lower waveguide core layer **50** have been applied. The substrate **20** and the layers **30** and **50** form a carrier for applying the first intermediate layer **60**, to which the second intermediate layer **70** is subsequently applied.

The layers **30**, **50**, **60** and **70** mentioned may have been grown onto the substrate **20** epitaxially, for example.

After the layers **30**, **50**, **60** and **70** have been applied, a ridge **R** having a width of 5-100  $\mu\text{m}$ , preferably 25  $\mu\text{m}$ , is etched into the structure, the longitudinal direction of said ridge extending along the z-direction. The etching depth of the ridge is chosen such that the latter is significantly greater than the total thickness of the layers **90**, **100** and if appropriate **110** applied epitaxially in further production steps, preferably greater than 1  $\mu\text{m}$ . The ridge structure is shown by way of example in FIG. **3**. The first intermediate layer **60** is exposed laterally as a result of the etching step.

After the etching of the ridge structure **R**, the first intermediate layer **60** is oxidized from outside, as shown by arrows **P** in FIG. **4**. As a result of the oxidation of the first intermediate layer **60**, the outer oxidized layer regions **62** are formed, which enclose the non-oxidized inner semiconductor region **61** of the first intermediate layer **60**.

The materials of the layers **30**, **50** and **70** are preferably composed of a different material than the first intermediate layer **60**, such that exclusively or at least primarily an oxidation of the first intermediate layer **60** is effected during the oxidation. By way of example, the material of the layer **30** can be AlGaAs or InGaP semiconductors, the material of the layers **50** and **70** can be AlGaAs or GaAs semiconductors and the material of the first intermediate layer **60** can be AlGaAs semiconductors. The Al content of the intermediate layer **60** is chosen in the growth direction at least in sections as >80%, but preferably as 100%, in order to ensure an efficient oxidation.

An automatic centering of the inner semiconductor region **61** relative to the two edges **R1** and **R2** of the ridge **R** occurs during the oxidation step. What is achieved by this automatic alignment is that the fundamental mode **120** (cf. FIG. **1**) of the electromagnetic radiation will be guided centrally between the edges **R1** and **R2** of the ridge **R**. An axis of symmetry of the component **10** along the z-axis is thus formed in a self-aligning manner.

FIG. **4** furthermore reveals that a strain both of the first intermediate layer **60** and of the second intermediate layer **70** situated thereabove occurs on account of the step of oxidation of the first intermediate layer **60**. A slight elevation **E** having a height of preferably 1 to 10 nm arises in the region above the inner semiconductor region **61** of the first intermediate layer **60** when the abovementioned materials are used.

In the context of further production steps (cf. FIG. **5**), the third intermediate layer **80** and the further layers **90**, **100** and **110** are applied to the second intermediate layer **70** strained in this way. By means of a suitable material selection and process control when applying the third intermediate layer **80**, what can be achieved is that the nanostructures **130** are formed in the region of the elevation **E**, in particular in the region of the outer edges of the elevation **E**. The formation of the nanostructures **130**, with an achievable lateral accuracy of  $\pm 50$  nm to  $\pm 1$   $\mu\text{m}$ , is based on the mechanical strain within the second intermediate layer **70**, caused by the oxidation of the first intermediate layer **60**.

In other words, the step of oxidation of the first intermediate layer **60** achieves not only a lateral waveguiding for the electromagnetic radiation, but furthermore also an automatic alignment of the nanostructures **130** above the inner semiconductor region **61** on account of the mechanical stresses that occur.

The further layers **90** and **100** are applied preferably likewise epitaxially. The upper contact layer **110** can be deposited epitaxially or applied in some other way.

For the materials of the layers **30**, **50**, **60**, **70**, **80**, **90** and **100**, the following material parameters are regarded as advantageous:

Layer **30**: AlGaAs, Al content between 10% and 30% or between 65% and 80%, alternatively InGaP having an In content of 45% to 52% (but preferably 48%), n-doped, layer thickness between 100 nm and 3000 nm, doping between  $5 \times 10^{17} \text{ cm}^{-3}$  and  $5 \times 10^{18} \text{ cm}^{-3}$ ,

Layer **50**: GaAs or AlGaAs, n-doped, layer thickness between 50 nm and 500 nm, doping between  $1 \times 10^{14} \text{ cm}^{-3}$  and  $1 \times 10^{17} \text{ cm}^{-3}$ ,

Layer **60**: AlGaAs, Al content preferably 100%, can also contain a composition gradient or composition steps, n-doped, layer thickness between 10 nm and 100 nm, doping between  $5 \times 10^{16} \text{ cm}^{-3}$  and  $5 \times 10^{17} \text{ cm}^{-3}$ ,

Layer **70**: GaAs, undoped, layer thickness between 20 nm and 500 nm,

Layer **80**: InGaAs or InAs, layer thickness between 0.2 nm and 50 nm, undoped,

Layer **90**: GaAs, undoped, layer thickness between 50 nm and 500 nm, doping between  $1 \times 10^{14} \text{ cm}^{-3}$  and  $1 \times 10^{17} \text{ cm}^{-3}$ ,

Layer **100**: AlGaAs, Al content between 10% and 30% or between 65% and 80%, alternatively InGaP having an In content of 45% to 52% (but preferably 48%), p-doped, layer thickness between 100 nm and 3000 nm, doping between  $5 \times 10^{17} \text{ cm}^{-3}$  and  $5 \times 10^{18} \text{ cm}^{-3}$ .

The layers are preferably grown epitaxially. Suitable process parameters for a growth method in the gas phase are, for example:

Layer **30**: Substrate temperature  $700^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $1 \mu\text{m/h}$ , starting substances trimethylaluminum (TMA), trimethylgallium (TMG), arsine ( $\text{AsH}_3$ ), ratio of the partial pressures of  $\text{AsH}_3$  to TMG and TMA (V/III ratio)  $>200$ ,

Layer **50**: Substrate temperature  $700^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $1 \mu\text{m/h}$ , starting substances TMG and  $\text{AsH}_3$ , V/III ratio  $>100$ ,

Layer **60**: Substrate temperature  $700^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $1 \mu\text{m/h}$ , starting substances TMG, TMA and  $\text{AsH}_3$ , V/III ratio  $>200$ ,

Layer **70**: Substrate temperature  $700^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $1 \mu\text{m/h}$ , starting substances TMG and  $\text{AsH}_3$ , V/III ratio  $>100$ , and

Layer **90**: Substrate temperature  $600^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $1 \mu\text{m/h}$ , starting substances TMG and  $\text{AsH}_3$ , V/III ratio  $>100$ .

The epitaxy steps for growing the third intermediate layer **80** and the nanostructures **130** can be implemented for example as follows:

Baking: Substrate temperature  $730^\circ \text{C}$ ., duration 10 min.,  $\text{AsH}_3$  partial pressure 1 mbar,

Layer **80**: Substrate temperature  $600^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $0.3 \mu\text{m/h}$ , starting substances TMG and  $\text{AsH}_3$ , V/III ratio  $>100$ , and

Nanostructures **130**: Substrate temperature  $500^\circ \text{C}$ ., reactor pressure 100 mbar, growth rate  $0.1 \mu\text{m/h}$ , starting substances TMG, trimethylindium and  $\text{AsH}_3$ , V/III ratio  $>5$ .

For all the layers, tertiary butylarsenic (TBAs) can be used as an alternative to  $\text{AsH}_3$ . Particularly at lower growth temperatures of  $450^\circ \text{C}$ . to  $600^\circ \text{C}$ ., TBAs can be advantageous on account of its thermal properties (reduced decomposition temperature). The ratio of the partial pressures of TBAs to TMG and TMA (TBAs/III ratio) is preferably between 1 and 40.

The oxidation step for the marginal oxidation of the first intermediate layer **60** can be implemented for example as follows:

Step 1: Photolithographic definition of an etching mask (e.g. composed of photoresist or silicon nitride) of one or more mesa strips having a width of  $15\text{--}50 \mu\text{m}$ .

Step 2: Wet-chemical or dry-chemical etching for exposing the lateral strip surfaces.

Step 3: Wet-chemical removal of the etching mask.

Step 4: Oxidation of the layer **70** in a nitrogen/water vapor atmosphere at  $350^\circ \text{C}$ . to  $450^\circ \text{C}$ ., preferably at  $420^\circ \text{C}$ ., substrate temperature. The reactor pressure is approximately 50 mbar, for example, and the flow rate for nitrogen is 3 liters/min, for example. The oxidation rate is set for example to  $0.5 \mu\text{m/min}$  by corresponding flow of the water vapor.

Step 5: Cleaning of the sample in an oxygen plasma.

FIG. 6 shows an exemplary embodiment of a vertically emitting electro-optical component **200**. The component comprises layers **30** to **110** which can be identical, for example, to those of the component **10** in accordance with FIG. 1. However, the layers **30** and **100** can also be replaced in each case by a periodic layer stack comprising e.g. 5-30 times (AlGaAs/GaAs) having layer thicknesses of the individual layers of between e.g.  $30\text{--}120 \text{ nm}$ , in order to produce a vertically reflective resonator structure.

In contrast to the component **10**, in the case of the component **200**, a mesa structure **210** is etched instead of a ridge, the cross section of the mesa structure (viewed from above) being round, oval or angular, for example. The cross section is preferably circular, such that a ring-shaped boundary of the layer **61** is produced on account of the oxidation. This supports a uniform distribution of the nanostructures during the growth of the third intermediate layer **80**. The etching depth of the mesa structure is once again chosen such that the latter is significantly greater ( $>1 \mu\text{m}$ ) than the total thickness of the layers applied in subsequent production steps.

The electromagnetic radiation is coupled out along the arrow direction P through an opening **220** in the upper contact layer **110**.

FIG. 7 illustrates by way of example the profile of the surface strain V in percent on the surface of the second intermediate layer for two different diameters D of the elevation against the respective position X. It is assumed by way of example that the center of the elevation is situated at  $X=0 \mu\text{m}$ . A positive value for the surface strain V in FIG. 7 describes a tensile stress, whereas a negative value describes a compressive stress.

It can be discerned in FIG. 7 that in the case of a large diameter  $D=2 \mu\text{m}$  of the elevation the strain is highest in the region of the edges of the elevation and accordingly, during subsequent application of nanostructures, the latter grow exclusively or predominantly in the region of the edges. In the case of a large diameter, therefore, the central region above the elevation remains completely or almost completely free of nanostructures. Exemplary embodiments of components comprising nanostructures in the region of the outer edges of the elevation were explained above in association with FIGS. 1 to 6.

It can furthermore be discerned in FIG. 7 that in the case of a small diameter  $D=1\text{ }\mu\text{m}$  of the elevation, in contrast, the strain spreads over the entire elevation and is highest in the central region of the elevation, such that during subsequent application of nanostructures the latter are formed particularly in the central region of the elevation. FIGS. 8 and 9 show exemplary embodiments in which the nanostructures lie in the central region of the elevation on account of the small size of the elevation.

FIG. 8 reveals an exemplary embodiment of an edge emitting electro-optical component 10, which is a laser, for example. The nanostructures lie in the central region of the elevation on account of the small size of the elevation E. For the rest, the exemplary embodiment in accordance with FIG. 8 corresponds to the exemplary embodiment in accordance with FIG. 1.

FIG. 9 reveals an exemplary embodiment of a vertically emitting electro-optical component 10, which is a laser, for example. The nanostructures lie in the central region of the elevation on account of the small size of the elevation E. For the rest, the exemplary embodiment in accordance with FIG. 9 corresponds to the exemplary embodiment in accordance with FIG. 6.

#### LIST OF REFERENCE SIGNS

10 Edge emitting component  
 20 Substrate  
 30 Lower waveguide cladding layer  
 40 Waveguide core  
 50 Lower waveguide core layer  
 60 First intermediate layer  
 61 Inner semiconductor region  
 62 Oxidized layer region  
 70 Second intermediate layer  
 80 Third intermediate layer  
 90 Upper waveguide core layer  
 100 Upper waveguide cladding layer  
 110 Upper contact layer  
 120 Ellipse/fundamental mode  
 130 Nanostructure  
 200 Vertically emitting component  
 210 Mesa structure  
 220 Opening  
     D Diameter  
 E Elevation  
 R Ridge  
 R1,R2 Edge/Margin  
 P Arrow

The invention claimed is:

1. A method for producing an electro-optical component (10, 200) suitable for emitting electromagnetic radiation (120), wherein in the method

a first intermediate layer (60) is applied on a carrier,  
 a second intermediate layer (70) is applied on the first intermediate layer, and

after the second intermediate layer has been applied, a mesa or ridge structure is etched and the buried first intermediate layer is locally modified laterally from the outside of the mesa or ridge structure,

wherein as a result of the local modification of the buried first intermediate layer in a lateral direction a refractive index jump is produced which brings about a lateral wave guiding of the electromagnetic radiation (120) in the unmodified region of the first intermediate layer,

wherein the local modification of the first intermediate layer (60) causes a strain both in the first intermediate

layer (60) and in the second intermediate layer (70) situated thereabove and forms an elevation (E) in the region above an inner semiconductor region (61) of the first intermediate layer (60) and

wherein, after etching the mesa or ridge structure, a third intermediate layer (80) is applied to the second intermediate layer, wherein nanostructures (130) are formed on the second intermediate layer as a result of the strain in the first and second intermediate layers in the region of the outer edges of the elevation (E), due to the strain caused previously in the region of the outer edges of the elevation (E).

2. The method as claimed in claim 1, wherein the lateral diameter of the elevation (E) is greater than  $1.5\text{ }\mu\text{m}$  and preferably lies between  $1.5\text{ }\mu\text{m}$  and  $2.5\text{ }\mu\text{m}$ .

3. The method as claimed in claim 1, wherein the nanostructures (130) are formed on the second intermediate layer (70) in the central region of the elevation (E), due to the strain caused previously in the central region of the elevation (E).

4. The method as claimed in claim 3, wherein the lateral diameter of the elevation (E) is a maximum of  $1.5\text{ }\mu\text{m}$ .

5. The method as claimed in claim 1, wherein the third intermediate layer (80) forms the active zone in which radiation is generated.

6. The method as claimed in claim 1, wherein quantum dots or quantum films are formed as nanostructures (130).

7. The method as claimed in claim 1, wherein as a result of the local modification of the buried first intermediate layer (60) in a lateral direction a refractive index jump is produced symmetrically about an optical axis of the component and the lateral waveguiding is effected symmetrically with respect to the optical axis.

8. The method as claimed in claim 1, wherein the third intermediate layer (80) is grown epitaxially on the second intermediate layer (70) after the local modification of the first intermediate layer (60).

9. The method as claimed in claim 1, wherein a mechanical strain is locally induced in the second intermediate layer (70) and the third intermediate layer (80) as a result of the local modification of the first intermediate layer (60), said mechanical strain supporting or causing the formation of nanostructures (130) during the deposition of the third intermediate layer (80).

10. The method as claimed in claim 1, wherein a section of the second intermediate layer (70) is removed and

the buried first intermediate layer (60) is exposed at least in sections and the intermediate layer exposed at least in sections is chemically modified before the third intermediate layer (80) is grown epitaxially on the second intermediate layer (70).

11. The method as claimed in claim 10, wherein the chemically modified section (62) of the first intermediate layer (60) is electrically nonconductive and has a lower refractive index than the unmodified section (61) of the buried first intermediate layer.

12. The method as claimed in claim 1, wherein the electro-optical component is laterally monomodal or laterally multimodal with regard to the emitted electromagnetic radiation, and

the lateral mode or the lateral modes of the electromagnetic radiation is/are defined by the lateral waveguiding of the unmodified region (61) of the buried first intermediate layer (60).

13. The method as claimed in claim 1 wherein the electromagnetic radiation is generated exclusively or predominantly

**11**

in that region of the third intermediate layer (**80**) which is situated above the unmodified section (**61**) of the first intermediate layer (**60**).

\* \* \* \* \*

**12**